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(54) A device for measuring blood flow

(57) A device for measuring the flow of blood in the skin and in the tissue close to the skin comprises a probe (11) having spring-loaded pressure pads to maintain contact with the skin surface at a controlled pressure, an input optical fibre (15) for directing a beam of light from a laser (10) onto the skin surface (14) a further optical fibre (16) for receiving resultant scattered light, a photo detector (12) in which the received light is compared with a reference light wave, and in which an electrical signal is produced and fed to a processor (13) which converts it into an analysis of blood flow.

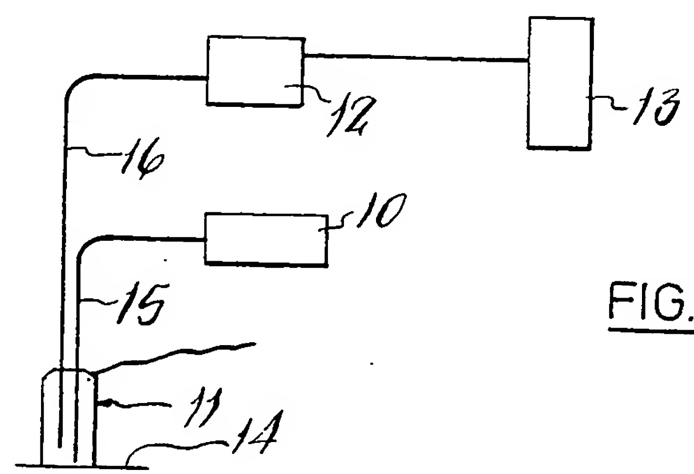

FIG.1

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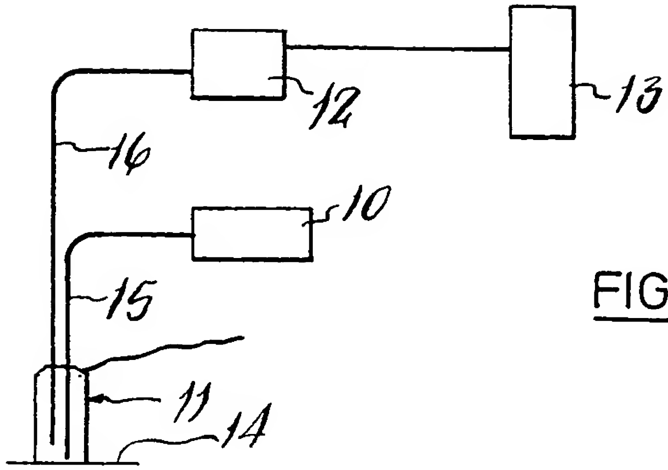

FIG.1

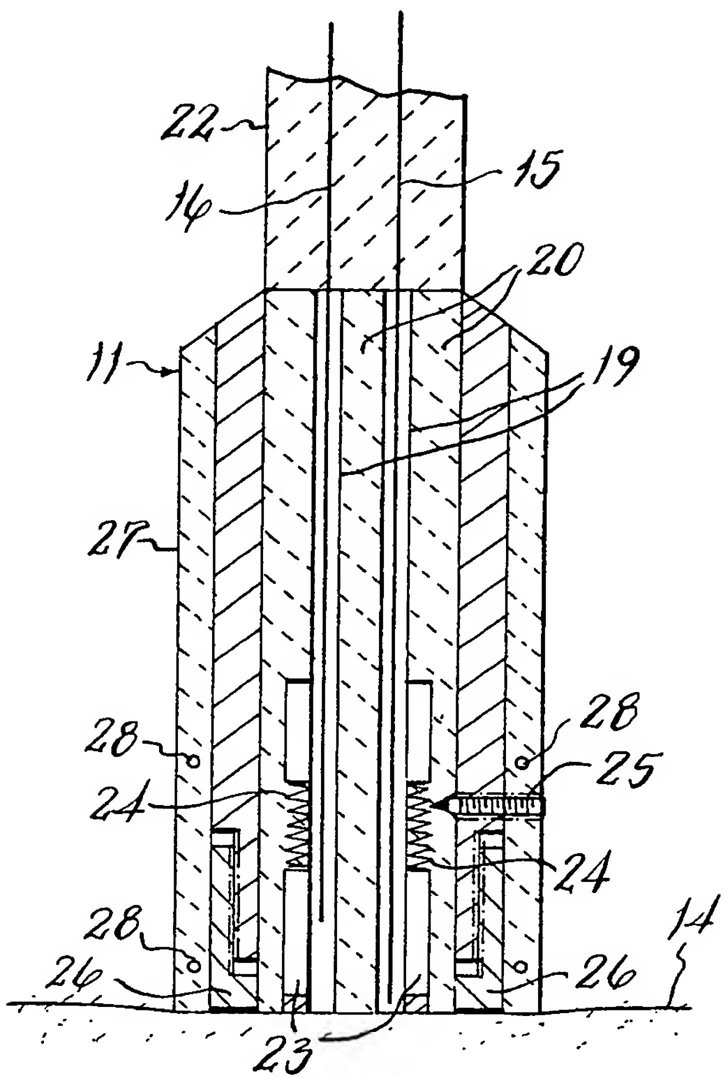

FIG.2

SPECIFICATION

A device for measuring blood flow

This invention relates to a device for measuring the flow of blood in the skin and in tissue close to the skin.

It is known that light radiation of a narrow bandwidth, such as that produced by a laser, when incident upon body tissue, is scattered by the red blood cells and by the connective tissue. The light scattered by the moving red blood cells has a different frequency from that of the incident light due to the movement of the cells, thus giving a Doppler shift to the scattered light. There is however no frequency shift for light scattered from the static connective tissue. Light scattered from a small volume of skin tissue has a fluctuating intensity, and determination of the fluctuating frequencies enables the characteristics of the blood flow to be detected and recorded.

The variation in frequency of the scattered light may be detected by mixing the light on a photodetector either with itself as a reference (known as homodyne detection), or with a separate reference light wave, for example the incident light beam (known as heterodyne detection). The signals must be mixed coherently so that they interfere, and this generates beat frequencies which are in the kilohertz region. The distribution of beat frequencies can be determined by analysis of the detector electrical output with a spectrum analyser or with an autocorrelator.

According to the present invention there is provided a device for measuring the flow of blood in the skin and in tissue close to the skin, comprising a probe, means in said probe for directing a beam of light of narrow band width, such as that produced by a laser, onto the skin surface, means for receiving resultant scattered light therefrom, a photodetector in which said received light is compared with a reference light wave and in which an electrical signal is produced representative of the comparison, and means for converting said electrical signal into an analysis of blood flow.

An embodiment of an instrument to detect and record blood flow in this manner, will now be described, by way of example only, with reference to the accompanying drawings, in which:—

Fig. 1 is a schematic illustration of the overall apparatus, and

Fig. 2 is an enlarged sectional view of a probe forming part of the apparatus.

As shown in Fig. 1, the apparatus comprises a laser light source 10, a probe 11, a photodetector 12, and an electronic processor 13 adapted to analyse and record readings detected by the probe.

The system operates by delivering incident light to a tissue surface 14 and receiving the scattered light from the tissue and transmitting it to the photodetector 12. Light from the laser 10 is coupled into an optical fibre 15 which transmits the light to the scattering site, the scattered light being collected by a receiving optical fibre 16 which is coupled to the photodetector 12. The laser 10 can be a gas laser or a laser diode. For maximum compactness and ease of handling, it is indeed preferable to use a laser diode with short length input and receiving fibres, and a photodetector detector.

It will be understood that the physical structure of the tissue at the scattering site is complex. The scattering process involves single and multiple scattering with the latter dominating and the scattering being from the static tissue and from the moving blood cells. The static parts include the connective tissue, the walls of the blood vessels and the somatic cells.

The probe 11 is arranged to detect the scattered light. In order to derive a signal which closely relates to blood flow and which is subjected to the minimum distortion, various factors must be taken into account, and these involve the optical fibre used; the position of the probe with respect to the surface; the pressure imposed on the surface by the probe; and the ambient temperature. The system must be deviced to produce a line width parameter in the case of frequency analysis, or a time decay parameter in the case of time autocorrelation analysis. Other factors of relevance are minimisation of base line instabilities, sensitivity to blood flow and reproducibility.

Referring now to Fig. 2, the probe will normally be used in contact with the tissue surface 14 so that the effect of vibrations is minimised. The optical fibres consist of input fibre 15 and receiving or output fibre 16. The fibres are disposed within small diameter metal tubes 19, disposed within a packing material 20. Above the main probe body 11 in the flexible lead 22 connecting the probe 11 to the remainder of the device, the fibres 15 and 16 are held within the packing material. The lower or outermost end of fibre 15 is terminated approximately one millimetre short of the adjacent end of its metal tube 19, in order to protect the fibre tip. The corresponding end of fibre 16 is terminated approximately 10 millimetres short of the end of its protective tube.

In use the scattered light is required to be collected within one coherence area. To achieve this, monomode or step-index, small diameter fibre can be used. Monomode fibre has a small core diameter (in the region of 5 micrometers) which ensures detection over one coherence area of the scattered light. This could also be obtained by incorporating a pin hole aperture in front of the receiving fibre but is more difficult and generally unsatisfactory. The spatial coherence of the input light should be maintained or made incoherent but not allowed to be partially coherent. Both multimode and monomode fibres can be used. The input fibre is preferably of step-index type having a diameter in the region of 250 micrometres. The receiving fibre is preferably of the monomode or step-index type and of small diameter as indicated above.

In order to achieve adequate scattered light signal, with optimum signal-to-noise ratio and time autocorrelation function or spectral line shape of optimum quality, the input and receiving fibres 15 and 16 should have a predetermined separation. It has been found experimentally that separation has a substantial effect on the detected signal, and an optimum spacing is in the region of 1.5 millimetres. For zero or low separations the frequency line width of the scattered light is at its smallest value since scattering from the tissue surface leads to a strong reference signal and heterodyne detection, and there is less multiple scattering from moving blood cells. The smallest separations are also more sensitive to the amount of blood in the tissue and to vibrations. For larger separations the detected signal involves a greater homodyne contribution and is less sensitive to vibrations. With large separations the scattered light intensity is too low and gives a poor signal.

The free end of the receiving fibre is separated from that of the input fibre by approximately 9 millimetres to ensure that the receiving fibre collects light over one coherence area without the need for a pin hole aperture. The height (d) of the end of the receiving fibre depends upon the diameter (a) of the end of the protecting tube 19 in which it is located, the core diameter (b) of the fibre and the wavelength of light (λ), according to the relation:—

$$1 < \frac{a \times b}{d \times \lambda} < 10$$

The probe incorporates a means of minimising signal distortion caused by pressure imposed on the scattering site. This feature enables uniform and repeatable pressure conditioning to be obtained. For this purpose, a pair of pressure pads 23 are urged downwardly towards the end of the probe by springs 24. A screw 25 permits adjustment of the spring pressure. The body of the probe includes a threaded end cap 26 which can be adjusted, again to vary the pressure applied by the pads 23 when the probe is brought into contact with the tissue surface 14 and the pressure pads are depressed until the base of the threaded portion 26 just makes contact with the surface. In this way, the pressure applied to the scattering site is maintained constant, and is adjustable.

The measured blood flow parameter is dependent upon the tissue temperature. Therefore, the probe 11 incorporates a temperature control means in the form of a small thermal jacket 27 with temperature sensors 28 therein and heaters (not shown) driven from an external power source.

Claims

1. A device for measuring the flow of blood in the skin and in tissue close to the skin, comprising a probe, means in said probe for directing a beam of light of narrow band width, such as that produced by a laser, onto the skin surface, means for receiving resultant scattered light therefrom, a photodetector in which said received light is compared with a reference light wave and in which an electrical signal is produced representative of the comparison, and means for converting said electrical signal into an analysis of blood flow.

2. A device according to Claim 1, including means for causing the probe to maintain contact with the skin surface with a controlled pressure thereon.

3. A device according to Claim 2, wherein said controlled pressure is ensured by a spring-loaded pressure pad and means for adjusting the spring pressure.

4. A device according to Claim 1, in which said reference light wave is equivalent to the beam of light directed onto the skin surface.

5. A device according to any preceding claim, in which a photodetector is arranged to mix the compared light waves coherently so that they interfere thus to generate beat frequencies in the kilohertz range, said converting means being a spectrum analyser or an autocorrelator.

6. A device according to any preceding claim, wherein said means for directing the beam of light onto the skin surface and the means for receiving the resultant scattered light therefrom are optical fibres, the incident beam of light being produced by a laser.

7. A device according to Claim 6, wherein the optical fibre directing the beam of light from the laser has a diameter in the region of 250 micrometers, whilst the optical fibre receiving the resultant light has a diameter in the region of 5 micrometres.

8. A device according to Claim 6 or Claim 7, wherein the optical fibre directing the beam of light from the laser is located in the probe with its free end terminated approximately 1 millimetre short of the end of the probe, and the optical fibre carrying the resultant light is terminated approximately 10 millimetres short of the end of the probe.

9. A device according to any one of Claims 6 to 8, wherein said optical fibres are spaced apart by approximately 1.5 millimetres.

10. A device according to any one of Claims 6 to 9, wherein said optical fibres are located in separate metal tubes which are disposed within packing material within the probe.

11. A device according to any one of Claims 6 to 10, wherein the optical fibre directing the beam of light from the laser is of the step-index type, and the optical fibre carrying the resultant light is of the monomode type.

12. A device according to any preceding claim, wherein said probe is surrounded by a thermal jacket having heaters therein and temperature control sensors thus to maintain a constant optimum temperature in the probe.

13. A device for measuring the flow of blood in

the skin and in tissue close to the skin, substantially as hereinbefore described, with reference to and as illustrated in the accompanying drawings.

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